The role of water in the stability of cratonic keels

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Cratons are typically underlain by large, deep, and old lithospheric keels (to > 200 km depth, > 2.5 Ga old) projecting into the asthenosphere (e.g., Jordan, 1978; Richardson et al., 1984). This has mystified Earth scientists as the dynamic and relatively hot asthenosphere should have eroded away these keels over time (e.g., Sleep, 2003; O'Neill et al., 2008; Karato, 2010). Three key factors have been invoked to explain cratonic root survival: 1) Low density makes the cratonic mantle buoyant (e.g., Poudjom Djomani et al., 2001). 2) Low temperatures (e.g., Pollack, 1986; Boyd, 1987), and 3) low water contents (e.g., Pollack, 1986), would make cratonic roots mechanically strong. Here we address the mechanism of the longevity of continental mantle lithosphere by focusing on the water parameter. Although 'nominally anhydrous', olivine, pyroxene and garnet can accommodate trace amounts of water in the form of H bonded to structural O in mineral defects (e.g., Bell & Rossman, 1992). Olivine softens by orders of magnitude if water (1-1000 ppm H_2O) is added to its structure (e.g., Mackwell et al., 1985). Our recent work has placed constraints on the distribution of water measured in peridotite minerals in the cratonic root beneath the Kaapvaal in southern Africa (Peslier et al., 2010). At P > 5 GPa, the water contents of pyroxene remain relatively constant while those of olivine systematically decrease from 50 to less than 10 ppm H_2O at 6.4 GPa. We hypothesized that at P > 6.4 GPa, i.e. at the bottom of the cratonic lithosphere, olivines are essentially 'dry' (< 10 ppm H_2O). As olivine likely controls the rheology of the mantle, we calculated that the 'dry' olivines could be responsible for a contrast in viscosity between cratonic lithosphere and surrounding asthenosphere large enough to explain the resistance of cratonic root to asthenospheric delamination.

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